Analysis and High-Resolution Modeling of Tropical Cyclogenesis During the TCS-08 and TPARC Field Campaign

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LONG-TERM GOALS

The long-term goal of this project is to improve the prediction of tropical cyclone (TC) genesis, structure and intensity changes through improved understanding of the fundamental mechanisms involved. Accurate prediction of TC genesis, structure and intensity changes is critical to Navy missions and civilian activities in coastal areas. Significant gains have been made in the TC track prediction over the past three decades. The genesis and intensity forecast, however, has shown very little progress during the same period. A main factor contributing to the lack of skill in the prediction of TC genesis and intensity is the lack of observations prior to and during TC genesis and intensification and the inadequate understanding of physical mechanisms that control the cyclogenesis and intensity change. The TCS-08 and TPARC field campaign provide an unprecedented opportunity for us to gain first-hand insight of observed characteristics of TC genesis in western Pacific and to compare them with high-resolution simulations. By analyzing and assimilating these data, we intend to understand the physical mechanisms including internal dynamic and thermodynamic processes, external forcing, and scale interactions. Only after we understand these processes, are we then able to tackle the weaknesses in model simulations and forecasts.

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14. ABSTRACT
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OBJECTIVES

The objective of this project is to conduct a thorough investigation on what initial precursor conditions (e.g., moisture vs. temperature vs. wind) are most critical for TC genesis, taking advantage of 2008 TCS-08 and TPARC observational products. We intend to produce a 3D high-resolution reanalysis product for the western North Pacific (WNP) during the intense observational campaign period, and to conduct COAMPS high-resolution cyclogenesis forecast with the use of the data assimilation products as initial conditions. We will in particular examine how the cyclogenesis forecast may be significantly improved with better descriptions of dynamic and thermodynamic precursor signals.

APPROACH

We plan to conduct the following two major tasks: 1) high-resolution TC genesis forecast and simulations to understand cyclogenesis mechanisms, and 2) typhoon reanalysis during the TCS-08 and TPARC campaign period to reveal 3D moisture and temperature structure and evolution characteristics prior to TC genesis.

For the first task, we will conduct high-resolution modeling to understand physical process associated with TC formation and identify key atmosphere variables for accurate prediction of tropical cyclogenesis. By diagnosing the model outputs, we will address science questions related to the observed moisture discharge and recharge and rainfall oscillation prior to TC genesis and fundamental difference between the “bottom up” genesis scenario and the “top down” scenario.

For the second task, because the TCS-08 and TPARC campaign provides variety types of data at irregular spatial and temporal intervals, we intend to construct a high-resolution regular-grid reanalysis product that combines all types of (field and remote-sensing) observations together. We plan to use NRL Atmospheric Variational Data Assimilation System (NAVDAS) or WRF 3DVar/4DVar to conduct the typhoon reanalysis. We are currently collaborating with NRL-MRY scientists (Dr. Nancy Baker) in implementing the direct satellite radiance assimilation technique into the COAMPS. The reanalysis will cover the entire TCS-08 and TPARC campaign period, with a horizontal resolution of 5-10 km and a time interval of 1-3 hours. Our assimilation strategy is to combine the in-situ observations (such as ELDORA radar, Doppler wind lidar, dropsondes and driftsondes) with multi satellite (such as Aqua and NOAA 15, 16 and 18) products.

WORK COMPLETED

The research of this year is focused on both real-case and idealized simulations of TC genesis in the western North Pacific. A real-case simulation of Typhoon Prapiroon has been conducted. The physical mechanism associated with this typhoon formation is attributed to the Rossby wave energy dispersion of a pre-existing TC. A manuscript is currently in preparation. Different from this typical "bottom-up" genesis scenario, another genesis scenario associated with a "top-down" development is also successfully simulated. Currently an intensive analysis of the model output is being carried out. While we are waiting for collecting observational campaign data products, we are collaborating with NRL data assimilation group to improve the NAVDAS satellite radiance assimilation.

RESULTS

A real-case TC genesis event of Typhoon Prapiroon (2000) in WNP is selected. This genesis is associated with Rossby wave energy dispersion of a pre-existing TC Bilis (2000). Using the reanalysis data as an initial condition, we successfully simulated this cyclogenesis event 3 days prior to the formation of Prapiroon. The simulated Rossby wave train bears many similarities as those from the observed (see Fig. 1). For example, the wavelength of the Rossby wave train is about 2500 km, and the vertical structure shows a baroclinic structure along the axis of the wave train. In addition to low levels, a significant wave train with alternating positive and negative vorticity perturbations appears at 200 hPa. The upper level flow is characterized by an intense asymmetric outflow jet.

Two sensitivity experiments are conducted to confirm the role of the Rossby wave energy dispersion from the pre-existing TC. In a control experiment (CTL), we retain both the pre-existing TC Bilis and its wave train in the model initial condition. In a sensitivity experiment (EXP), we remove the pre-existing TC Bilis while keeping its wave train. The numerical simulations demonstrated the important role of the pre-existing TC energy dispersion in the subsequent TC genesis. Based on the model diagnosis, we propose that both a direct and indirect processes are involved. The direct process is through the TC southeastward energy dispersion, by which the induces Rossby wave train triggers the convection-circulation feedback. The indirect process is through the upper tropospheric influence associated with the asymmetric outflow jet. On one hand, the outflow jet extends horizontally and enhances the divergence (convergence) tendency to the left (right)-exit of the jet due to weak inertial stability. The upper-level divergence superposing on the low-level cyclogenesis area may boost vigorous convective activities (Fig. 2). The prolific meso-scale vortices concentrate in

the cyclonic vorticity region, which helps create a primary vortex through vortex merging and the absorption of the vorticity of the convectively generated vortices, and thus favors TC-scale vortex development. On the other hand, the asymmetric outflow jet induces a well-organized cyclonic eddy momentum flux, which acts to drive the radial circulation and accelerates the growth of a new TC.

Different from the “bottom-up” genesis scenario above, another genesis scenario associated with “top-down” development was also successfully simulated using a cloud-resolving WRF model. Initially, a mid-level mesoscale vortex develops, in association with a “cold core” structure. We successfully simulated this type of genesis event. The simulation results suggest that the convective cells are responsible for the changes of the vortex in both dynamic and thermodynamics fields. These convective cells have a “vertical hot tower” structure. Once the convective cells were coupled to an updraft, the low-level convergence forced by the updraft brought these cells together, resulting in a more intense surface cyclone. This low-level vortex enhancement takes place within mesoscale convective systems (MCVs), before a TC-scale vortex has formed and the vortex has become self-sustaining through WISHE.

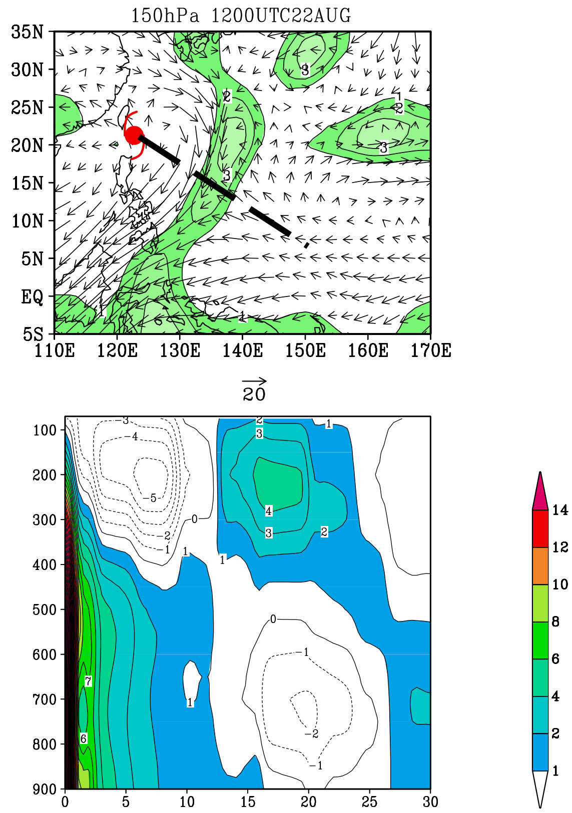

Fig. 1 The observed 150-hPa wind vector (m s^{-1}) and relative vorticity (unit: 10^{-5} s^{-1}) fields at 1200 UTC 22 August 2000 (top panel), and the vertical-radius cross-section of relative vorticity fields (bottom panel) along a northwest-southeast oriented axis (the dashed line).

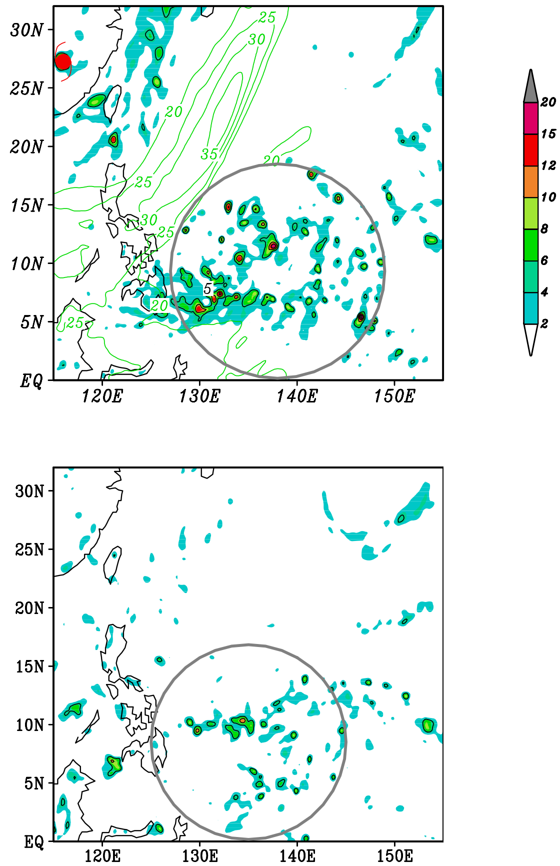

Fig. 2 The upper-level divergence (≥ 2×10^{-5} s^{-1} are shaded) and wind (contour interval: 5 m s^{-1}) fields at the jet core region in CTL (top panel) and EXP (bottom panel) at 1200UTC 24 August.

IMPACT/APPLICATIONS

The understanding of the cyclogenesis mechanisms and the improvement of NAVDAS data assimilation are critical to improve the NOGAPS and COAMPS predictions of TC genesis and TC intensity change.

TRANSITIONS

Results from this study may lead to improvements in the ability of NOGAPS and COAMPS to predict tropical cyclone genesis and intensity change, which may lead to a transition to 6.4 projects.

RELATED PROJECTS

This project is closely related to the ONR funding entitled “Western Pacific tropical cyclone reanalysis with the NRL Atmospheric Variational Data Assimilation System (NAVDAS)” in which we conduct the typhoon reanalysis for 2005-2007. Knowledge gained from this project will help assimilate TCS-08 and TPARC observational data and improve the model initial condition for TC prediction.

PUBLICATIONS

In the following we list the publications that are fully or partially supported by this ONR grant:

Peng, J., T. Li, and M. Peng, 2008: Formation of tropical cyclone concentric eyewalls by wave-mean flow interactions. *Advances in Geosciences*, Vol. 10, in press.

Ge, X., T. Li, Y. Wang, and M. Peng, 2008: Tropical Cyclone Energy Dispersion in a Three-Dimensional Primitive Equation Model: Upper Tropospheric Influence. *J. Atmos.Sci.*, **65** (7), 2272–2289.

Lin, A., and T. Li, 2008: Energy spectrum characteristics of boreal summer intraseasonal oscillations: climatology and variations during the ENSO developing and decaying phases. *J. Climate*, in press.

Zhang, Y.-S., and T. Li, 2008: Satellite-Observed 3-D Moisture Structure and Air-Sea Interactions during Summer Monsoon Onset in the South China Sea. *Advances in Geosciences*, Vol. 10, in press.

Qi, Y., R. Zhang, T. Li, and M. Wen, 2008: Interactions between the summer mean monsoon and the intraseasonal oscillation in the Indian monsoon region, *Geophys. Res. Lett.*, *35*, L17704, doi:10.1029/2008GL034517.

Chen, J.-M., T. Li, and J. Shih, 2008: Asymmetry of the El Niño-spring rainfall relationship in Taiwan. *J.M.S. Japan*, 86, 297-312.

Zhang, Y.-S., and T. Li, 2008: Influence of the Sea Surface Temperature in the Indian Ocean on the In-phase Transition between the South Asian and North Australian Summer Monsoons. *TAO*, in press.

Manuscript in preparation:

Ge, X., T. Li, and M. S. Peng, 2008: Cyclogenesis simulations of Typhoon Prapiroon (2000) associated with Rossby wave energy dispersion.